The AMS-02 detector on the ISS

Status and highlights after 11 years on orbit

ASI Agenzia Spaziale Italiana

INFN PERUGIA

V. Vagelli (ASI & INFN)
on behalf of the AMS collaboration

CRIS 2022
12th Cosmic Ray International Seminar
Naples, Italy, September 12 -16, 2022

AMS-02 has collected

209,033,541,836

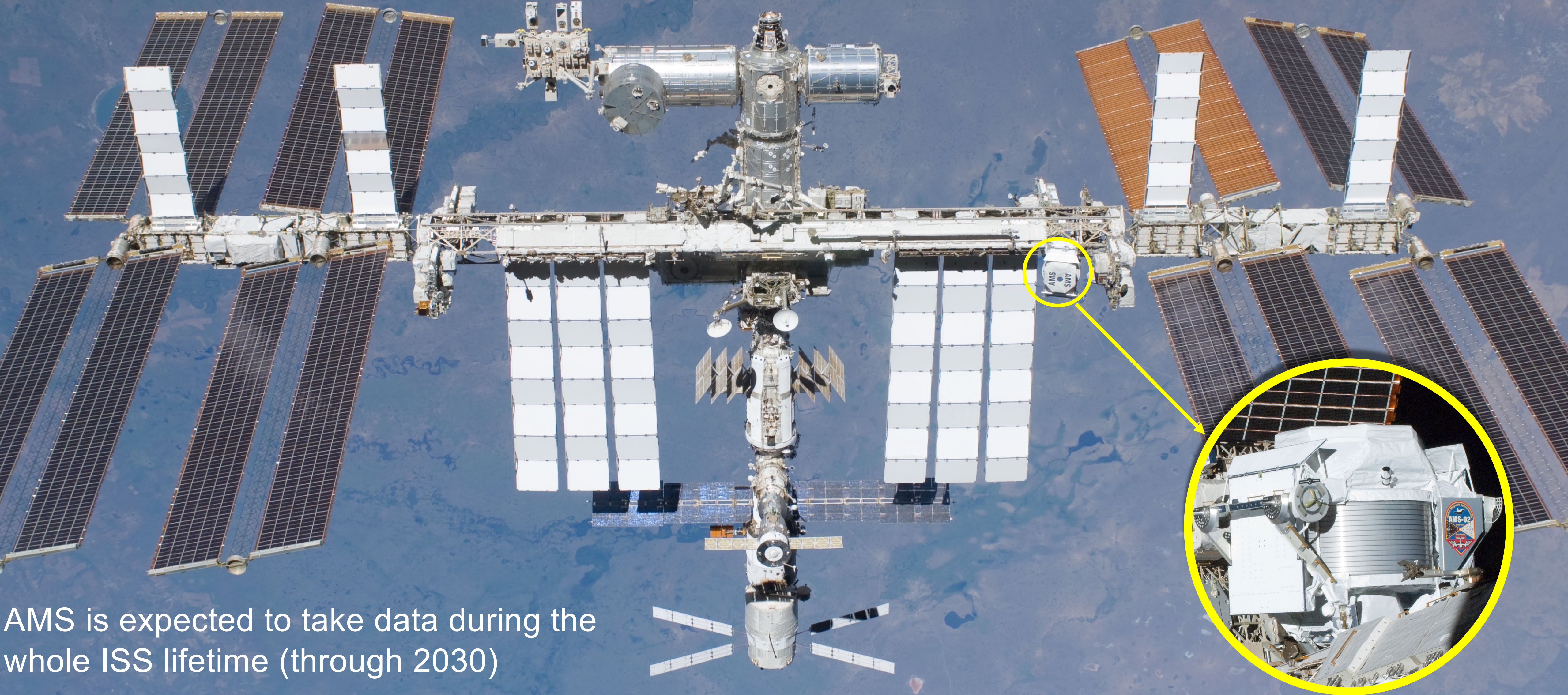
cosmic ray events

Last update: Sep 14, 2022, 8:02 AM

http://ams02.space/

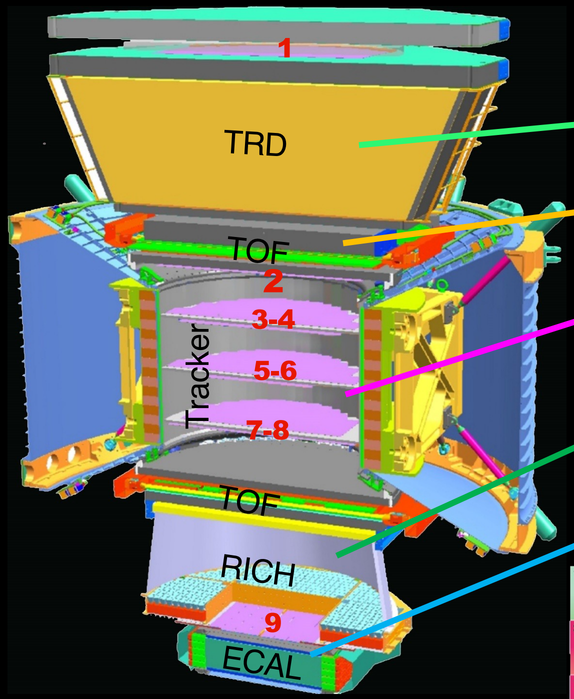
AMS-02 in orbit

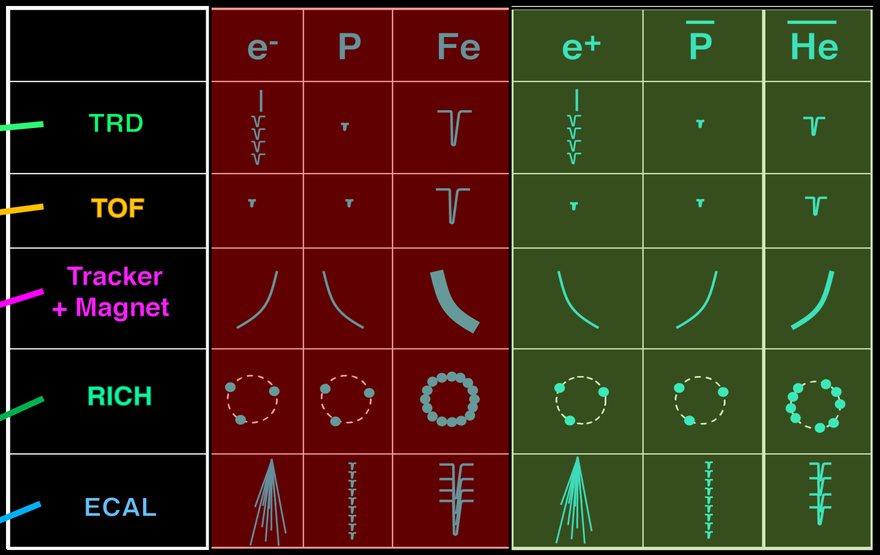
AMS-02 is a large-acceptance high-energy **magnetic spectrometer** capable of measuring accurately particles in the **GeV-TeV** energy range. Since **2011** May 19th AMS-02 has been operating on the International Space Station (ISS). AMS recorded **>200 billion CR triggers** in ~11 years of operation.

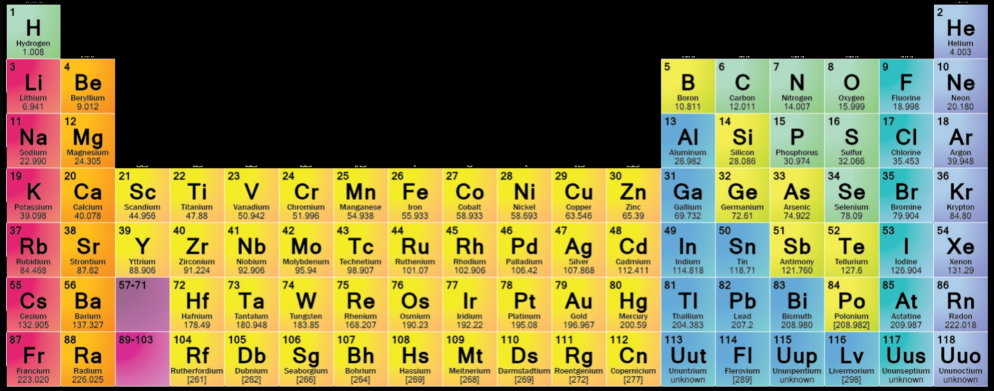


AMS is expected to take data during the whole ISS lifetime (through 2030)

Cosmic ray identification





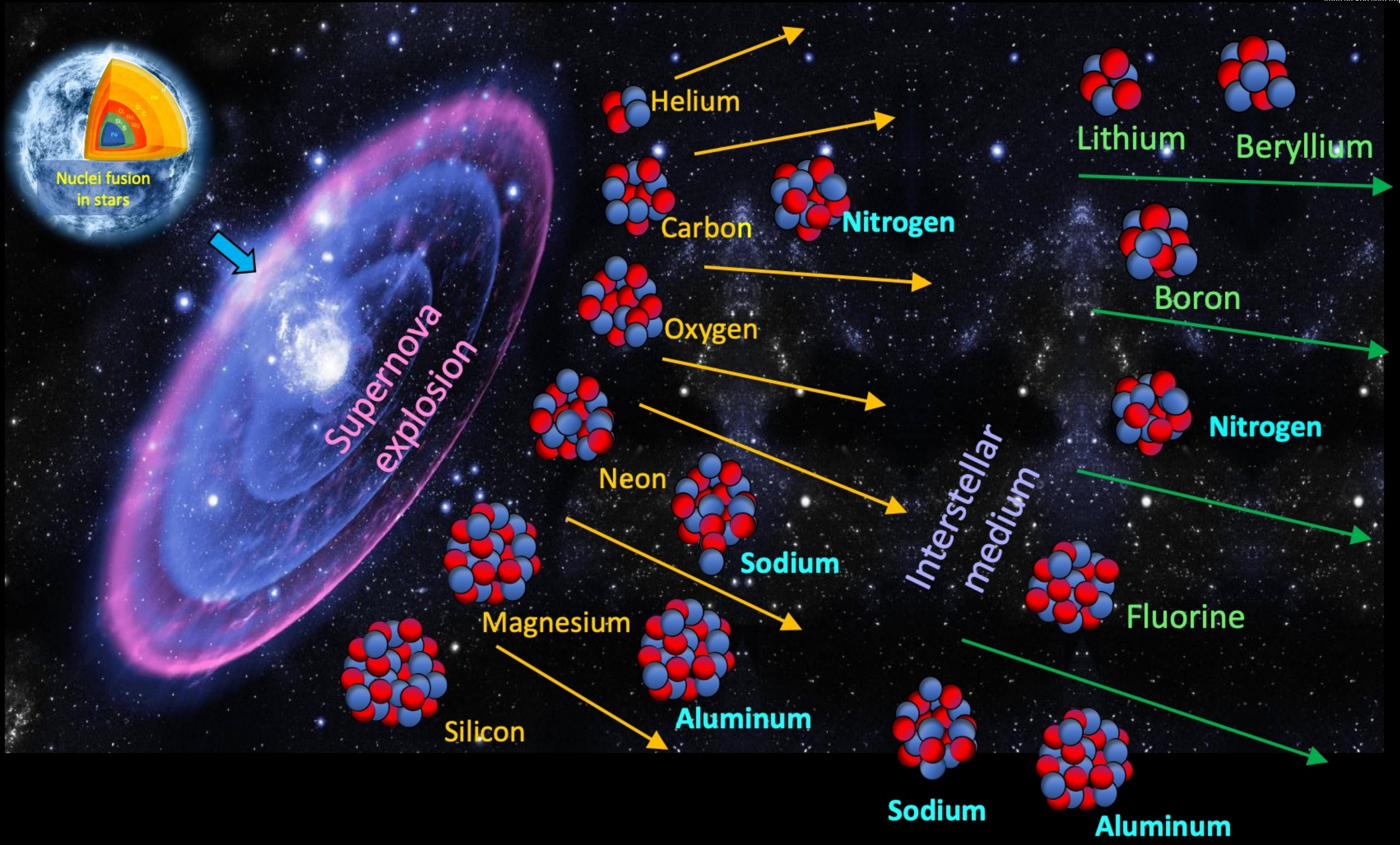


AMS measures :

- Momentum (P, GeV/c)
- Charge (Z)
- Rigidity (R=P/Z, GV)
- Energy (E, GeV/A)
- Flux (signals/(s sr m^2 GeV))

for matter and antimatter cosmic rays up to TeV energies

Origin, acceleration and propagation of cosmic rays



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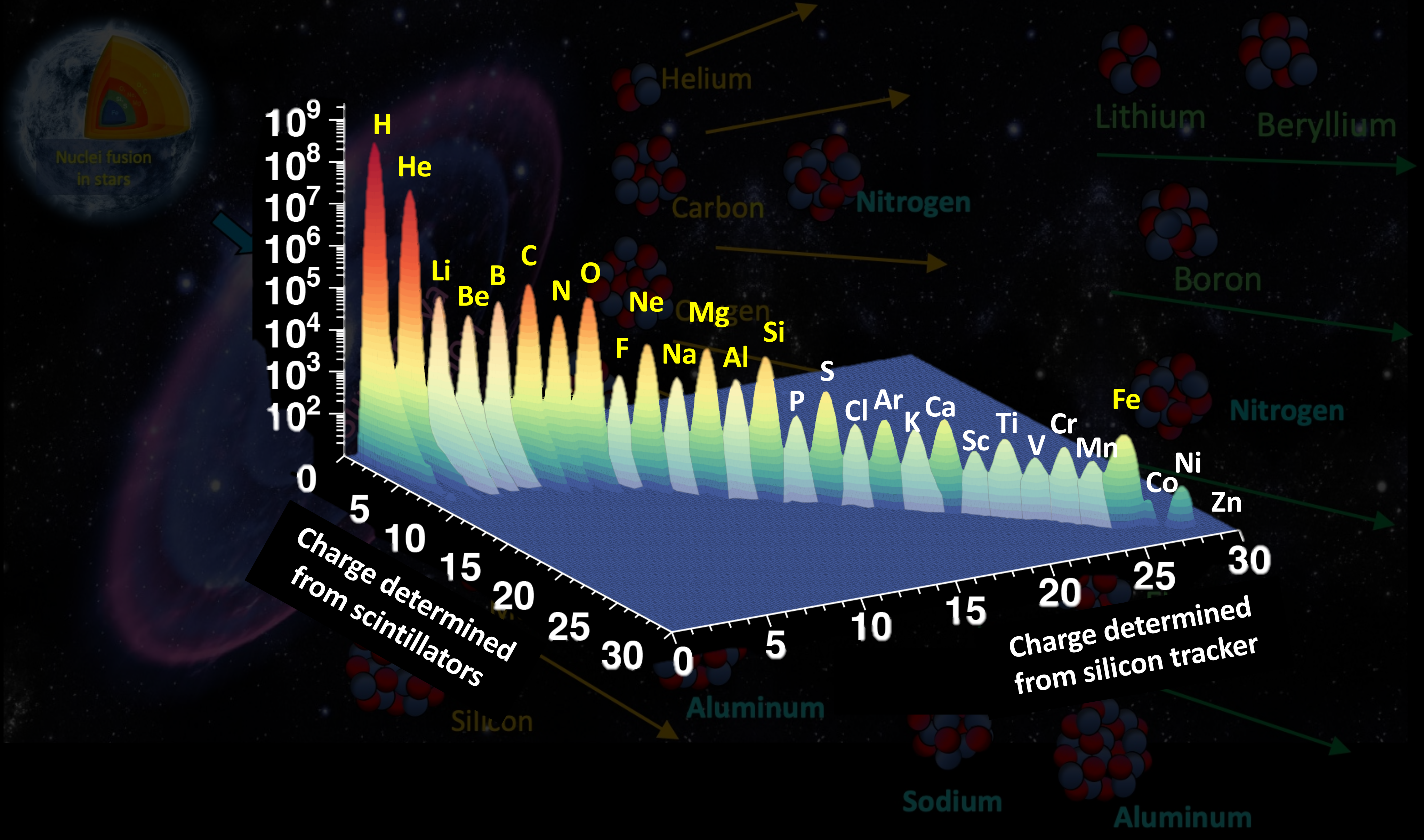
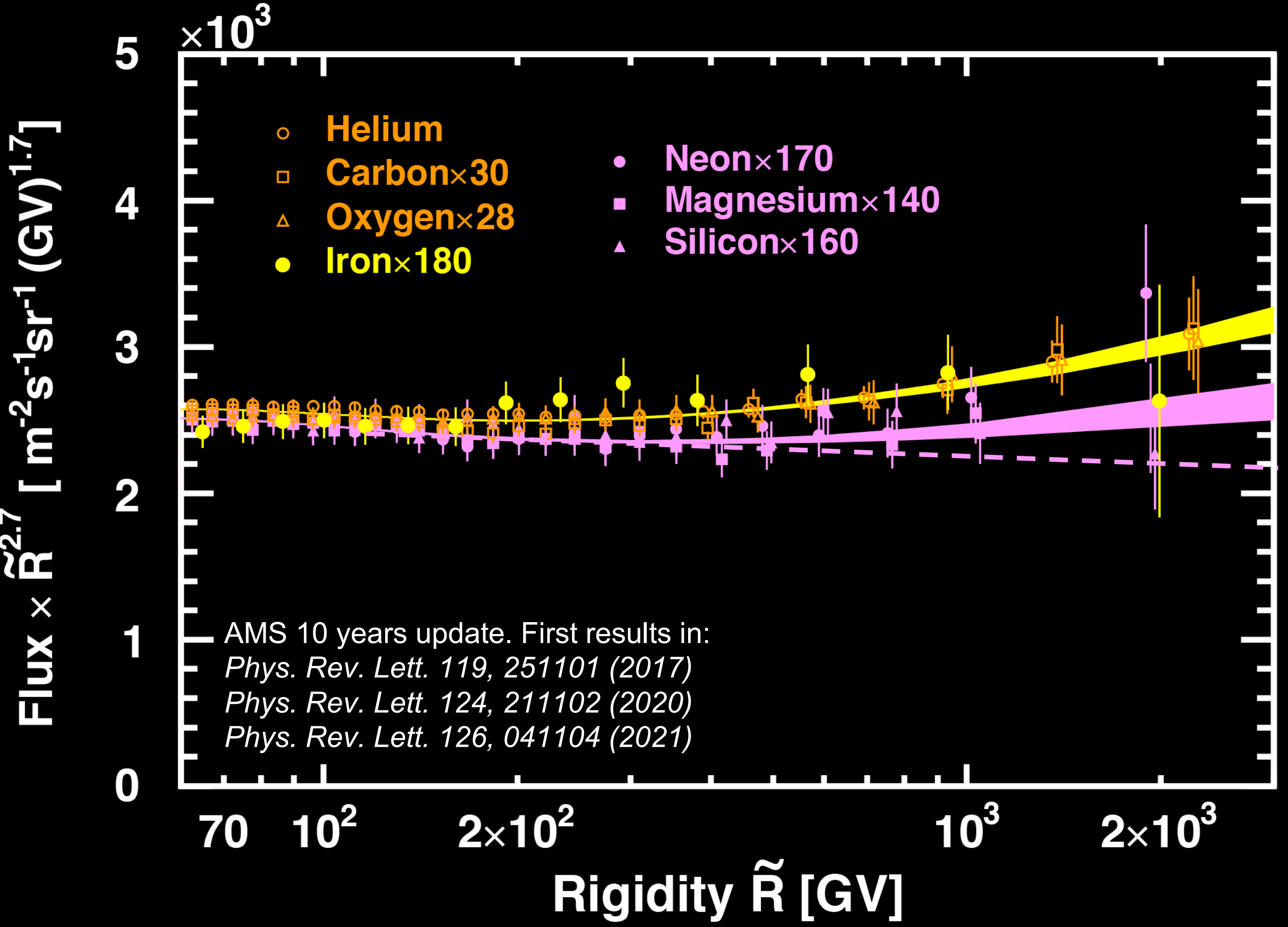


Measurement of cosmic ray nuclei



Primary elements (H, He, C, ..., Fe) are produced during the lifetime of stars. They are accelerated by the explosion of stars (supernovae).

Primary cosmic rays He, C, and O have identical rigidity (P/Z) dependence.

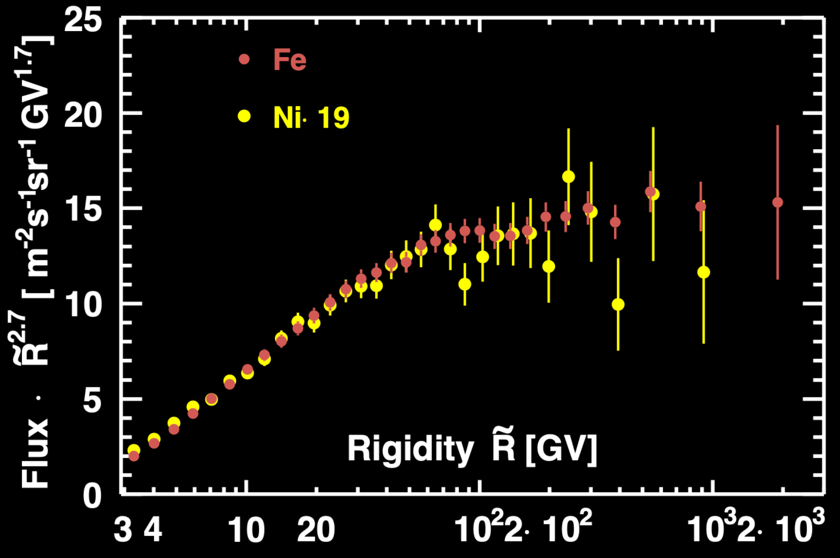
Heavier primary cosmic rays Ne, Mg and Si have their own identical rigidity behavior but different from He, C, O. **Primary cosmic rays have at least two classes.**

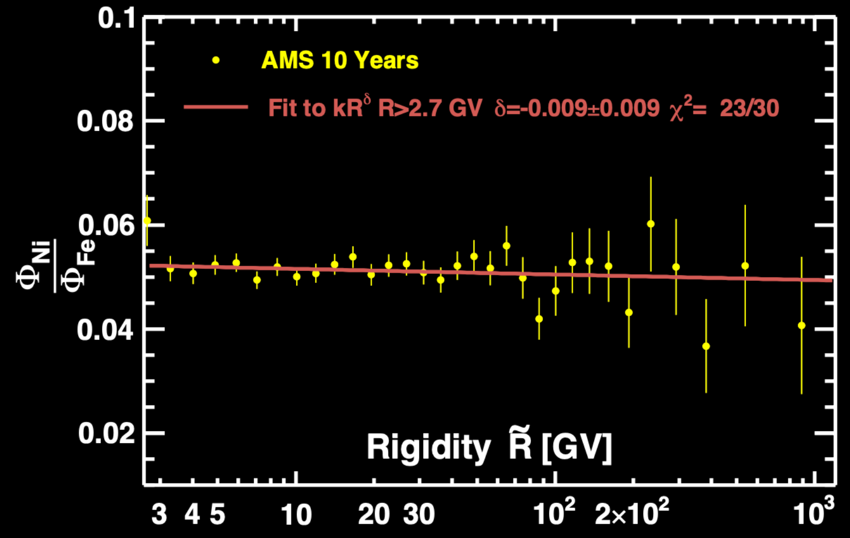
$$\gamma_{Ne,Mg,Si} = \gamma_{He,C,O} + (-0.042 \pm 0.007)$$

Iron is in the He, C, O primary cosmic ray group instead of the expected Ne, Mg, Si group.

Measurement of cosmic ray nuclei

Preliminary result. Please refere to forthcoming AMS publication on PRL





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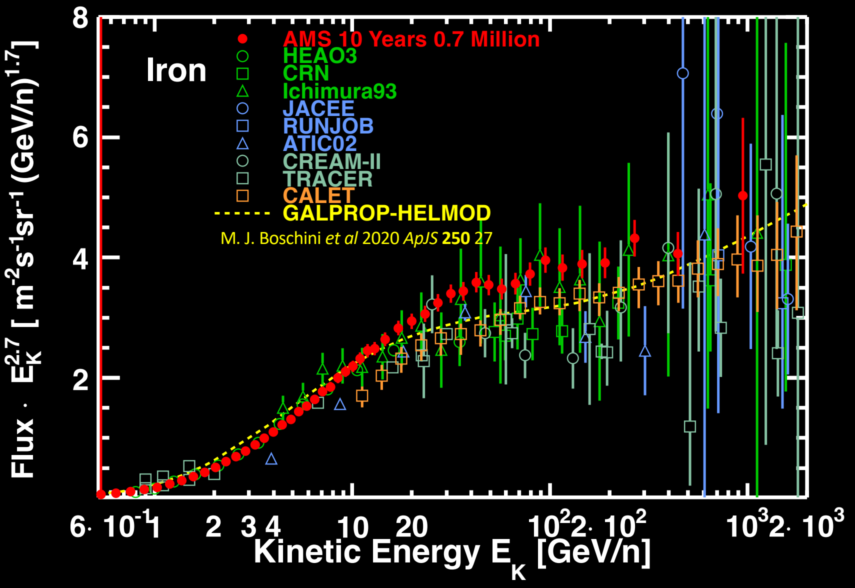
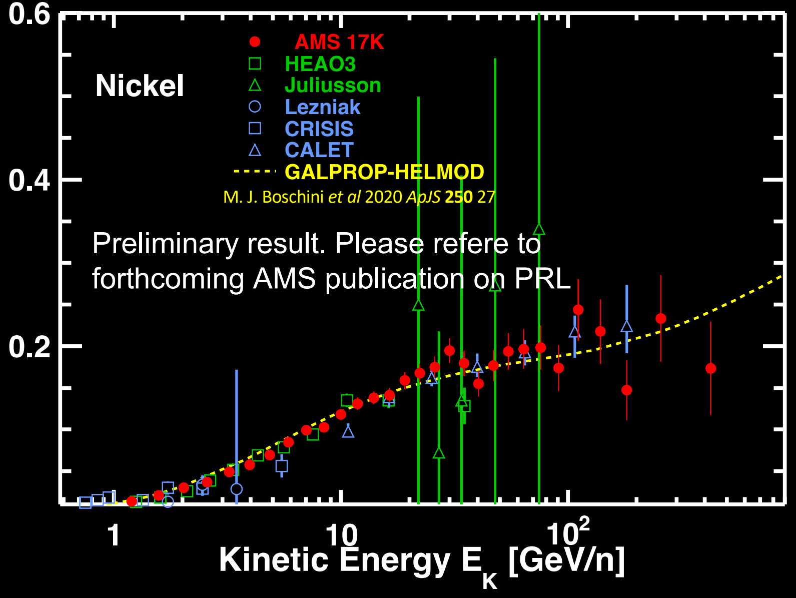
Nickel (Z=28) shows similar rigidity dependence to Iron

Measurement of cosmic ray nuclei





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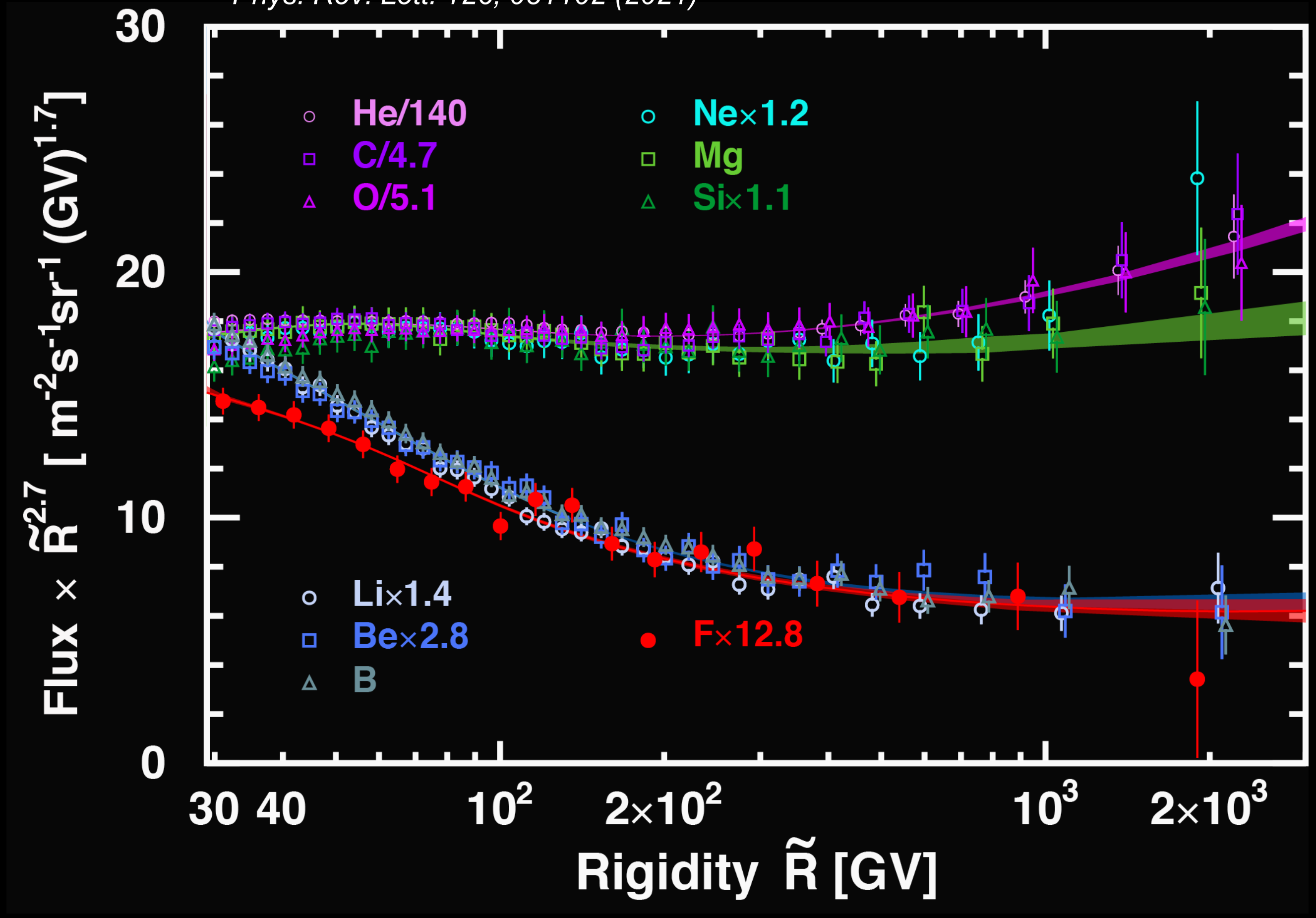
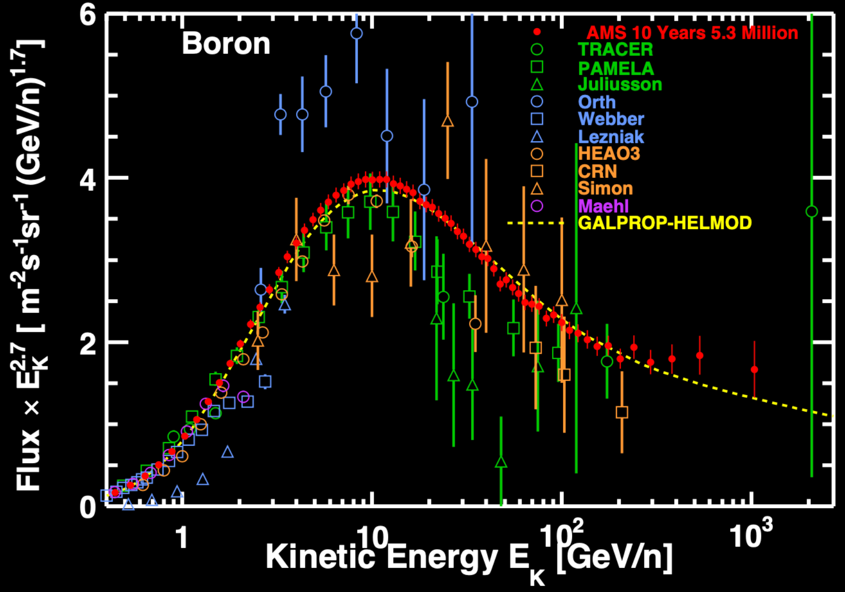
AMS 10 years update. First results in:
Phys. Rev. Lett. 120, 021101 (2018)
Phys. Rev. Lett. 126, 081102 (2021)

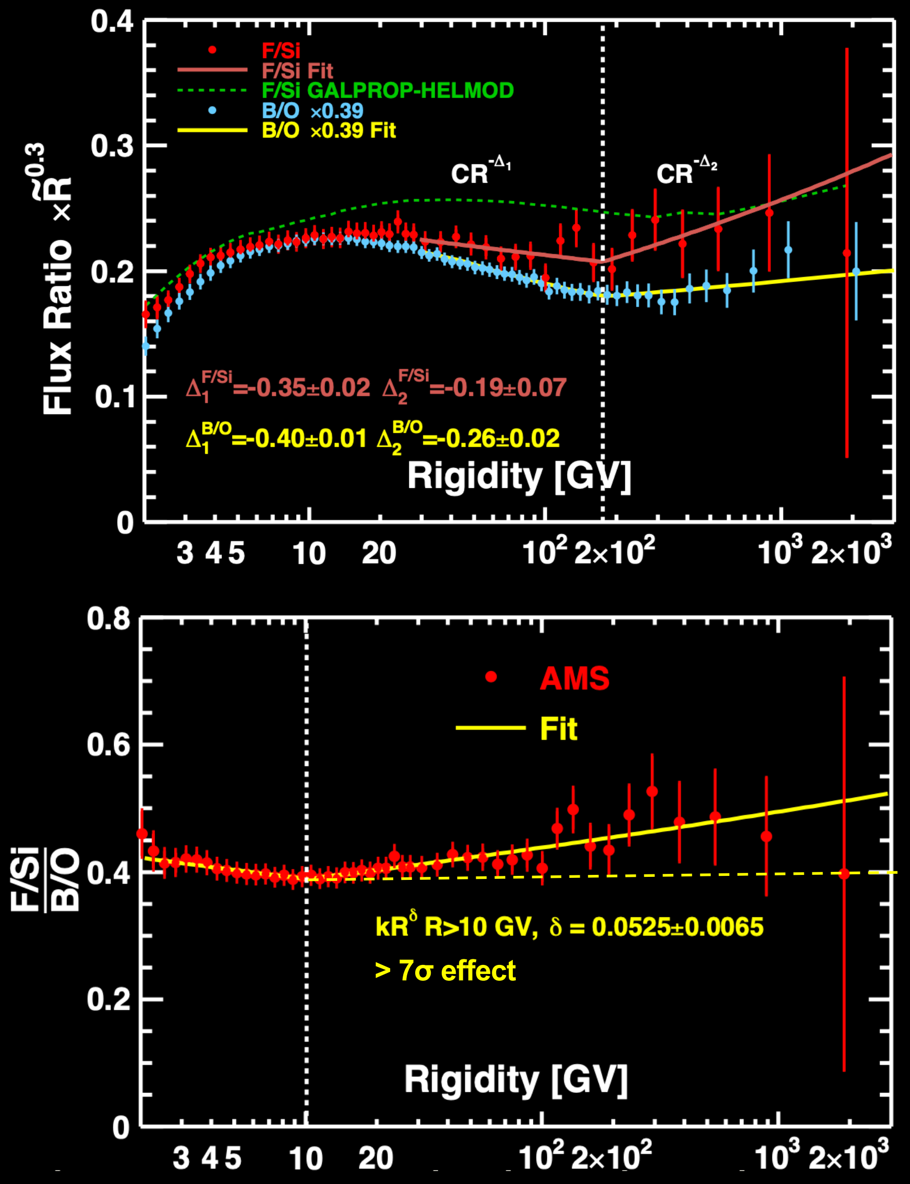


Secondary cosmic rays (Li, Be, B, F, ...) are produced by the collision of primary cosmic rays and interstellar medium.

Over the last 50 years, only few experiments had measured the Li and Be fluxes above a few GV. Typically, these measurements have errors larger than 50% at 50 GeV/n.



Measurement of cosmic ray nuclei



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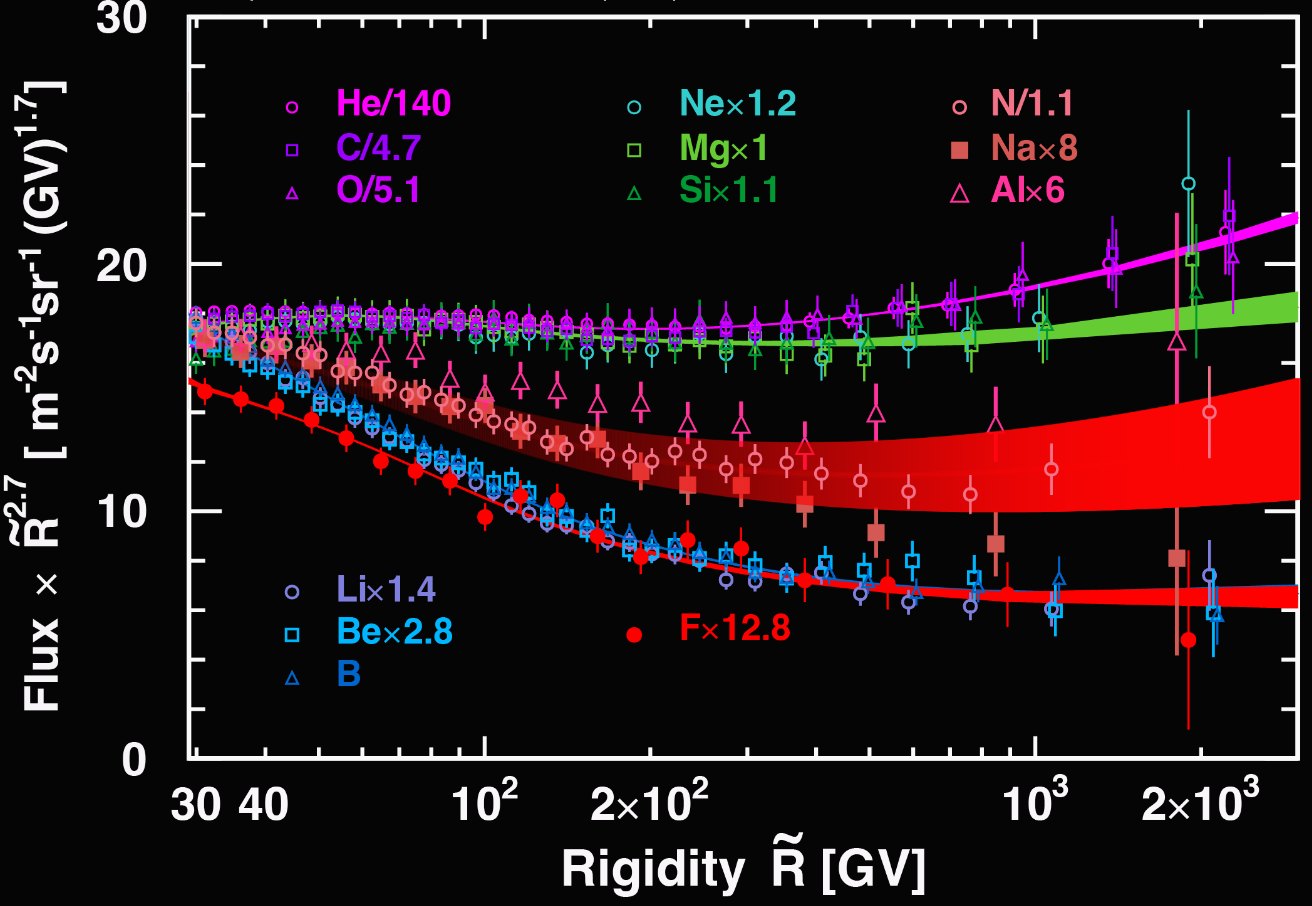
The **light secondary/primary ratios** are not a single power law: this favors the hypothesis that the observed spectral hardening is due to a propagation effect.

The **heavy secondary/primary ratio** F/Si has a different energy dependence from the light B/C ratio: secondary CRs have also two classes, and the propagation properties are different from heavy to light cosmic rays.

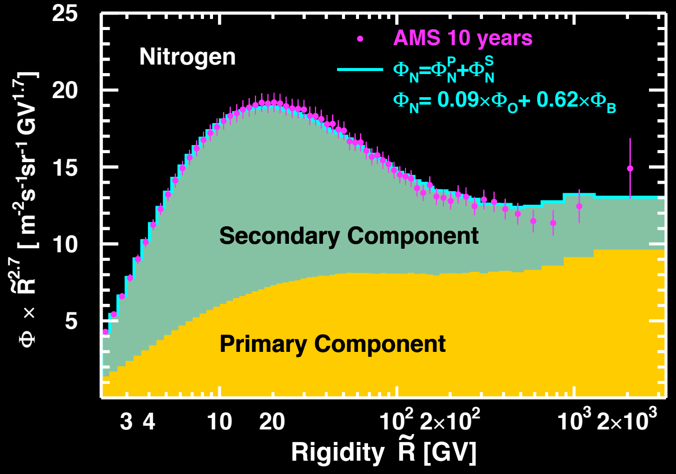
Measurement of cosmic ray nuclei

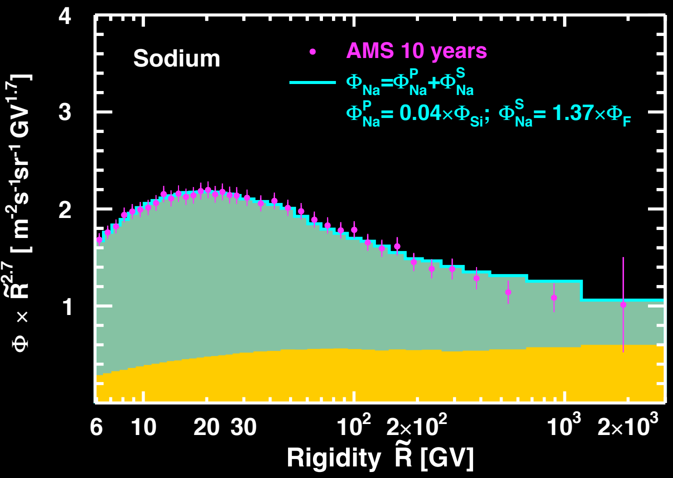
AMS 10 years update. First results in:
Phys. Rev. Lett. 121, 051103 (2018).
Phys. Rev. Lett. 127, 021101 (2021).

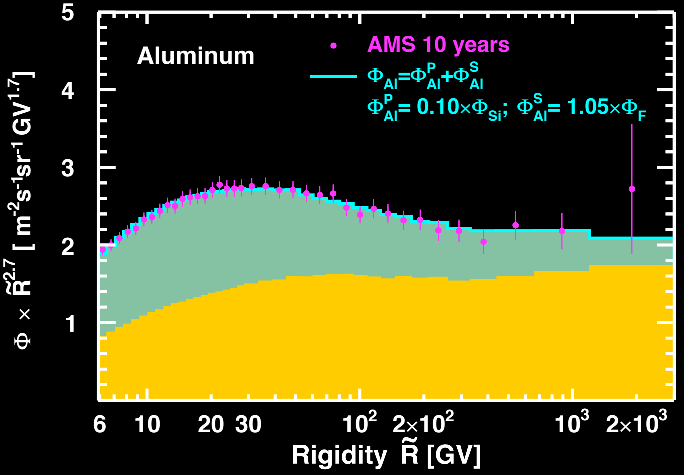


N, Na and Al nuclei are produced both in stars and by collisions of primary cosmic rays with the interstellar medium. They belong to a **third class of cosmic rays**, which is a combination of primary and secondary origin.

Measurement of cosmic ray nuclei







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N, Na and Al fluxes Φ_X can be described by a weighted sum of a primary component $\Phi_X^P \propto \Phi_{O,Si}$ and a secondary component $\Phi_X^S \propto \Phi_{B,F}$

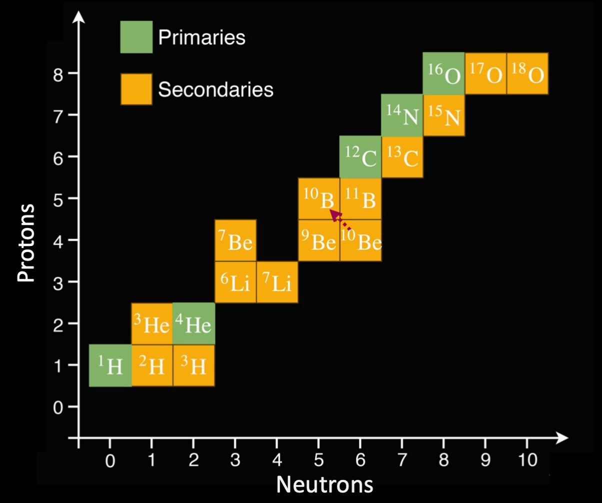
Also C, Ne, Mg and S require a small fraction (<5%) of a secondary component for their description.

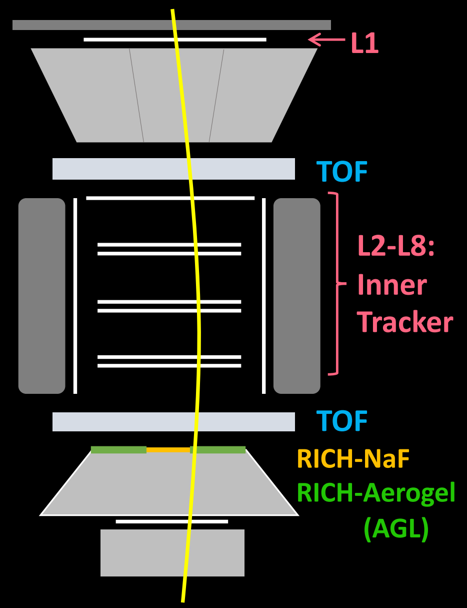
This allows the determination of the Φ_N^P/Φ_O, Φ_{Na}^P/Φ_{Si} and Φ_{Al}^P/Φ_{Si} abundance ratios at the source without the need to consider the Galactic propagation of cosmic rays.

Measurement of cosmic ray isotopes

Isotope studies give unique information on **propagation** (D, ^{3}He), **production mechanism** (^{6,7}Li, ^{7,9}Be) and independently measure the **age of cosmic rays** (^{9,10}Be).

- D and ^{3}He are mostly produced by the fragmentation of ^{4}He: simpler comparison with propagation models than heavier primary/seconday ratios
- Smaller cross-section of He: D/^{4}He and ^{3}He/^{4}He probe the properties of diffusion at larger distances
- ^{10}Be/^{9}Be provides more sensitive measurement of the age of cosmic rays than Be/B flux ratios



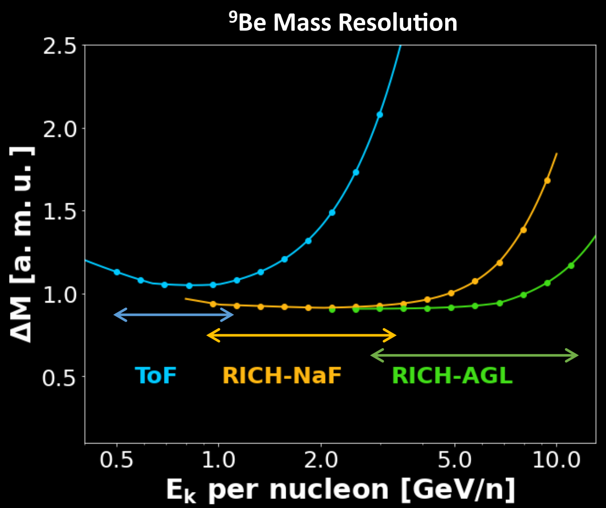


$$M = \frac{RZ}{\beta\gamma}$$

- R measurement :
  - Tracker, $\Delta R/R \sim 10\%$ at 10 GV
- β measurements:

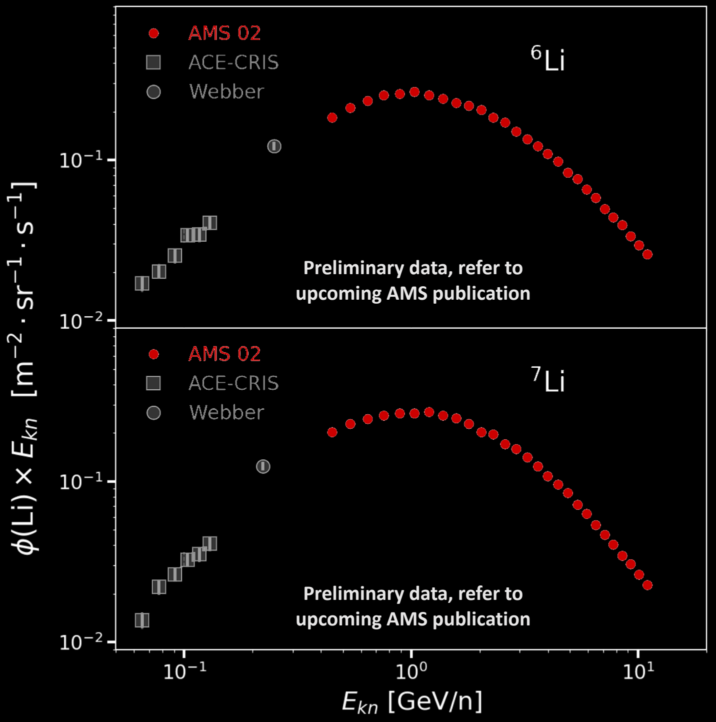
	E_{kn} range (GeV/n)	$\Delta\beta/\beta$ (Z=1)	$\Delta\beta/\beta$ (Z=4)
TOF	(0.5, 1.2)	~3%	~1.5%
RICH-NaF (n=1.33)	(0.8, 4.0)	~0.3%	~0.15%
RICH-AGL (n=1.05)	(3.0, 12)	~0.1%	~0.05%

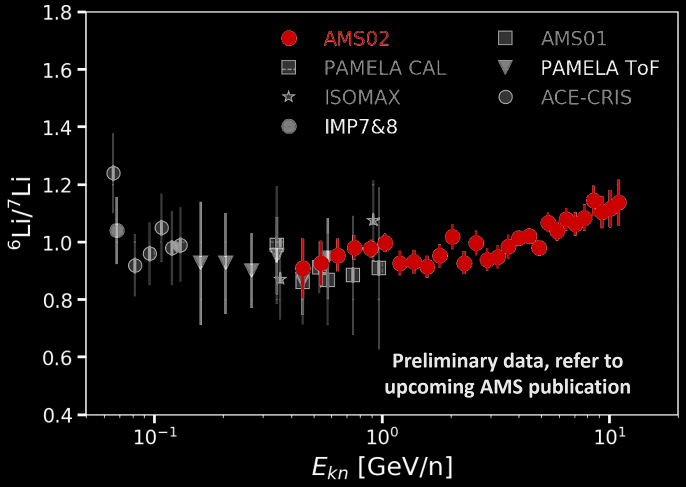
$$\frac{\Delta M}{M} = \sqrt{\left(\frac{\Delta R}{R}\right)^2 + \left(\gamma^2 \frac{\Delta\beta}{\beta}\right)^2}$$

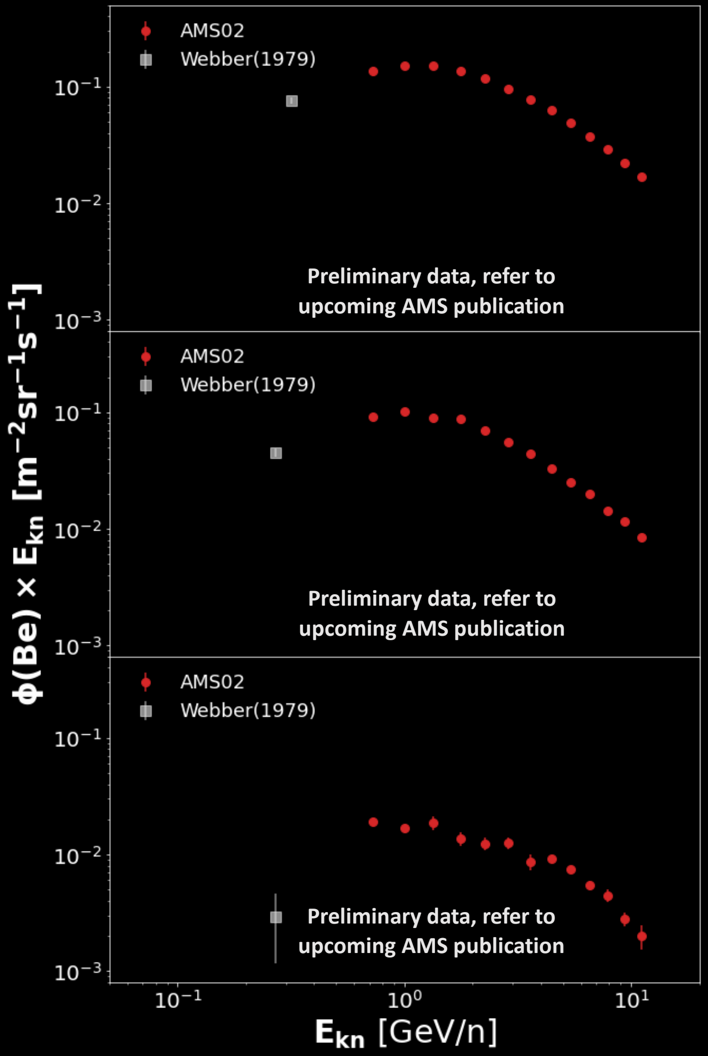


$\Delta M \sim 1$ a.m.u.→ Unable to do event-by-event isotope identification

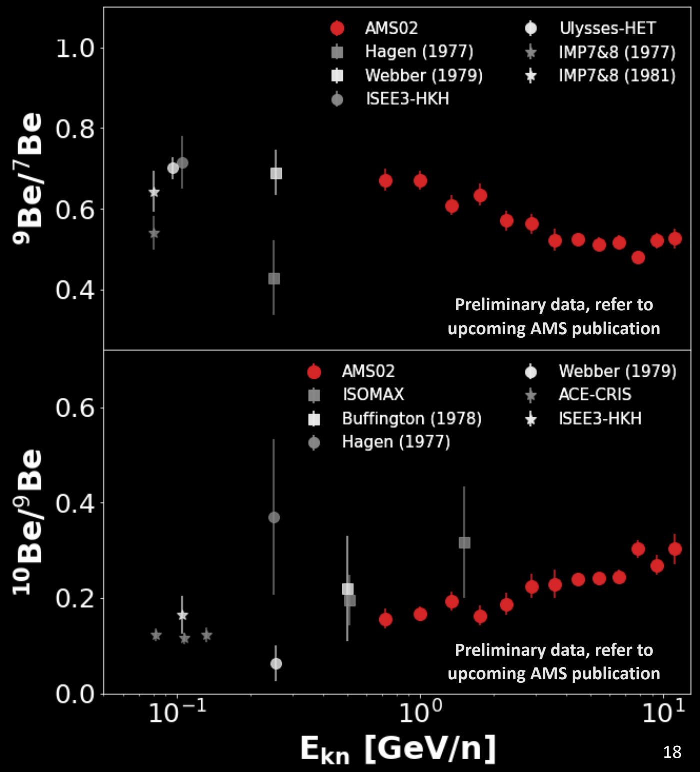
Measurement of cosmic ray isotopes





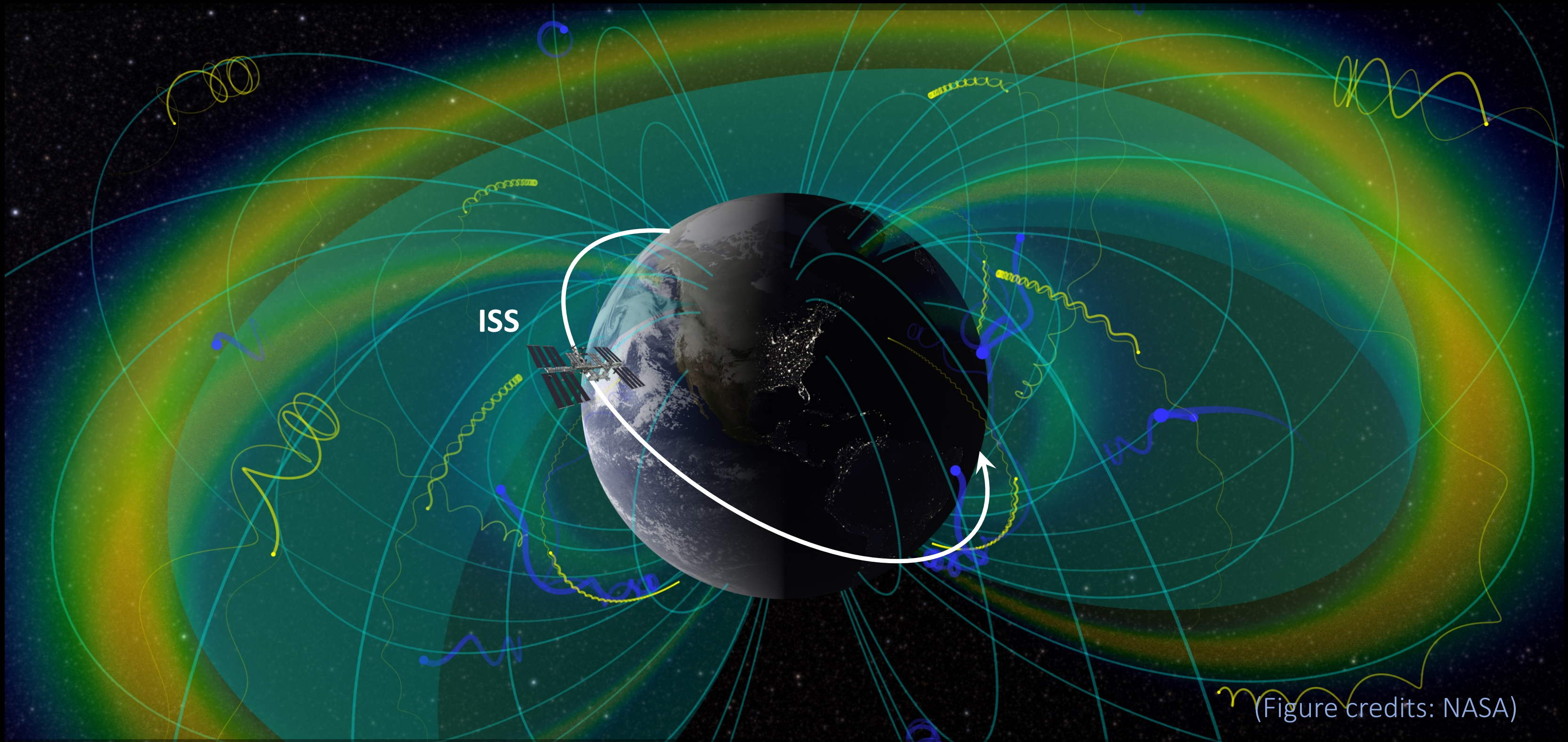


Preliminary data. Please refer to the AMS forthcoming publication



AMS-02 is exploring an uncharted energy region for the understanding of cosmic ray acceleration and propagation mechanisms

Cosmic rays in the magnetosphere



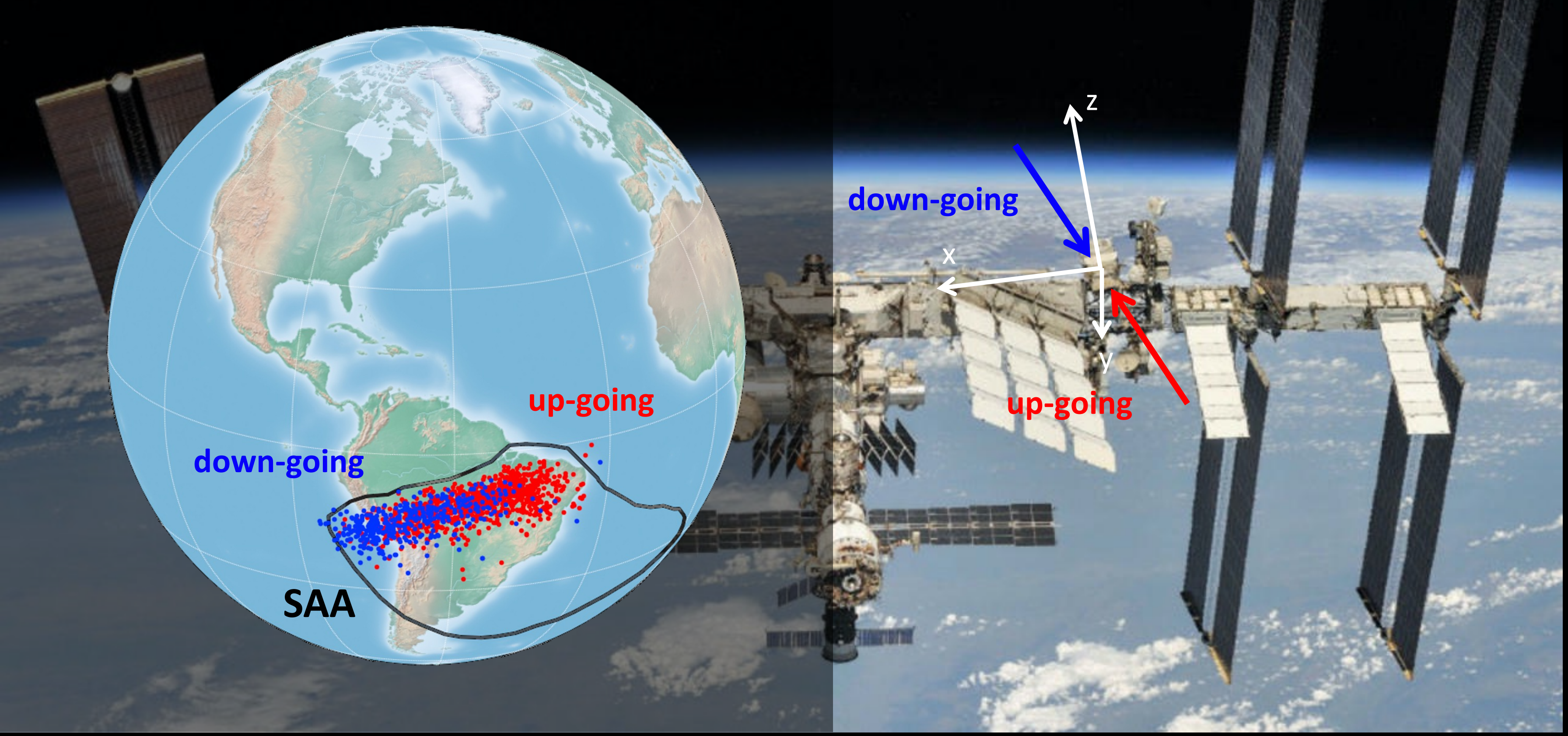
Particles **trapped** in the Earth magnetic field create regions of **high radiation** called **Van Allen belts**.
The **South Atlantic Anomaly (SAA)** is an area over South America where the inner belt dips down to an altitude of 200 km. The ISS crosses this region, causing a sudden increase of the observed radiation.

Energetic particles with charge up to Z=2 are known to exist in this region.
No previous observation of Z>2 energetic (> 1 GV) particles in SAA.

Stably Trapped Nuclei in the SAA

9

Backtracing allows to select particles stably-trapped in Earth's magnetosphere.
A clear population of stably trapped ions (Z>2) entering in AMS
both from the top and the bottom has been identified.



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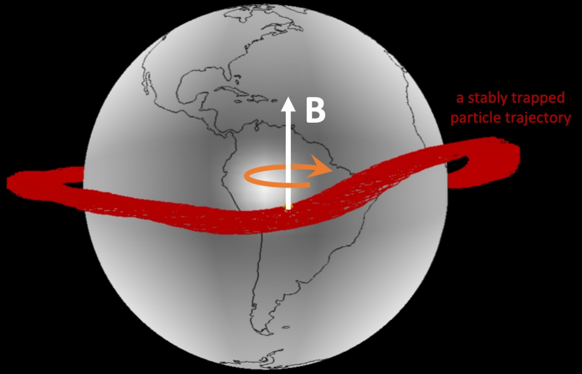

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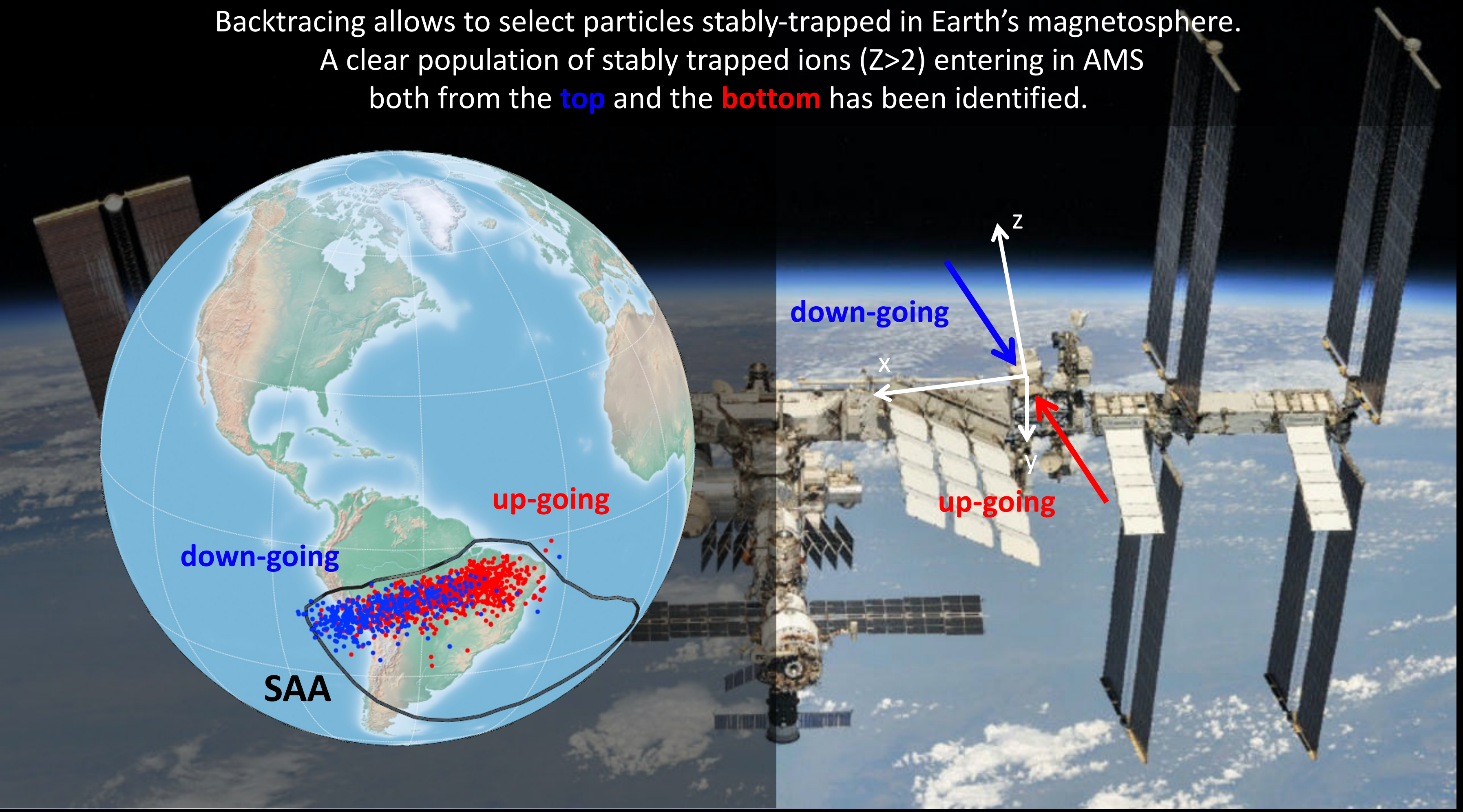
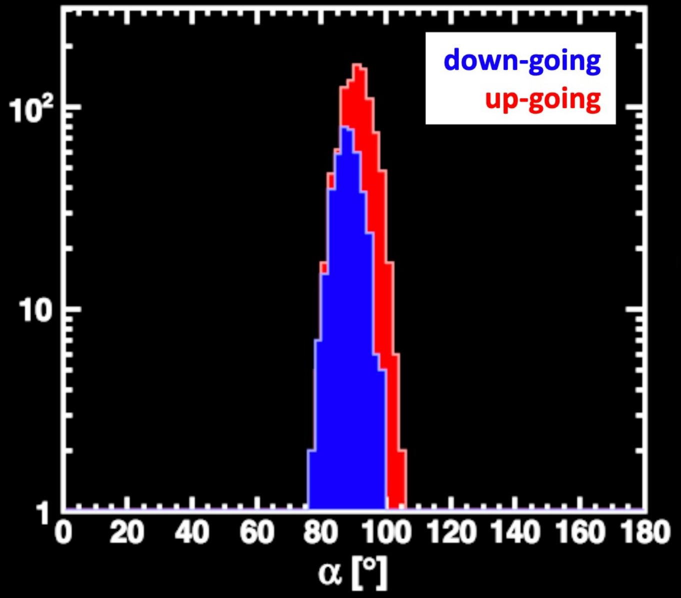
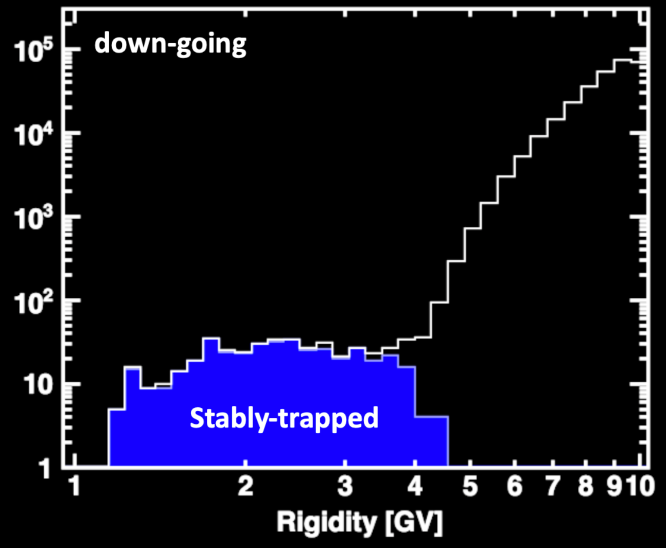


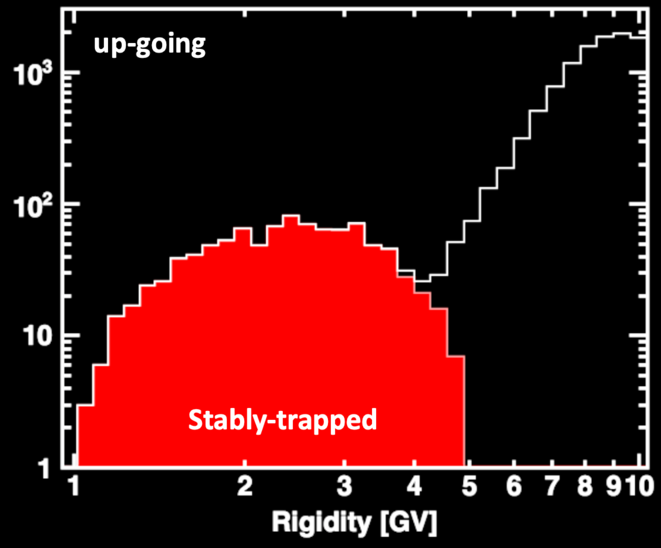


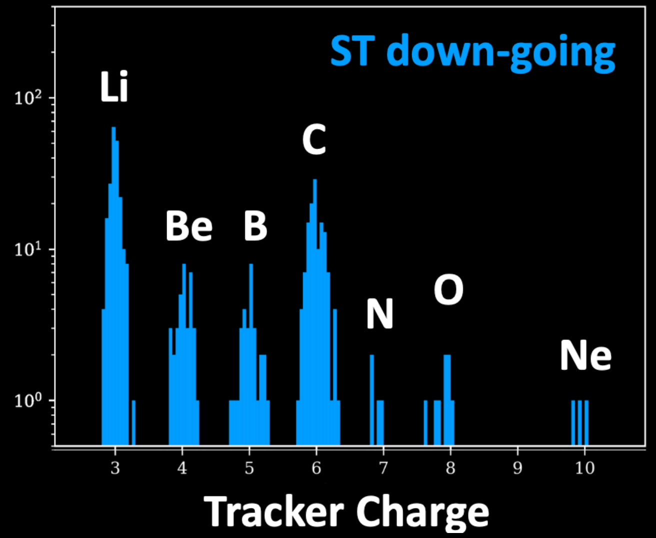
Pitch angle is the angle between particle and magnetic field. All stably-trapped ions have a pitch angle of about 90°.

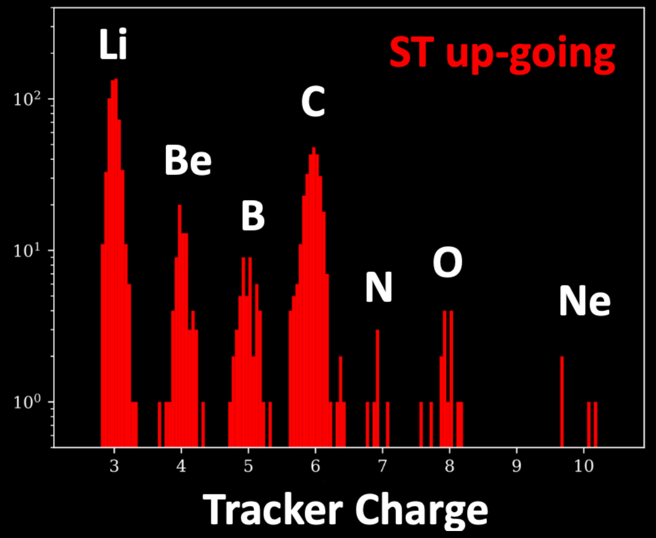
Cosmic rays in the magnetosphere

Preliminary data. Please refer to the AMS forthcoming publication









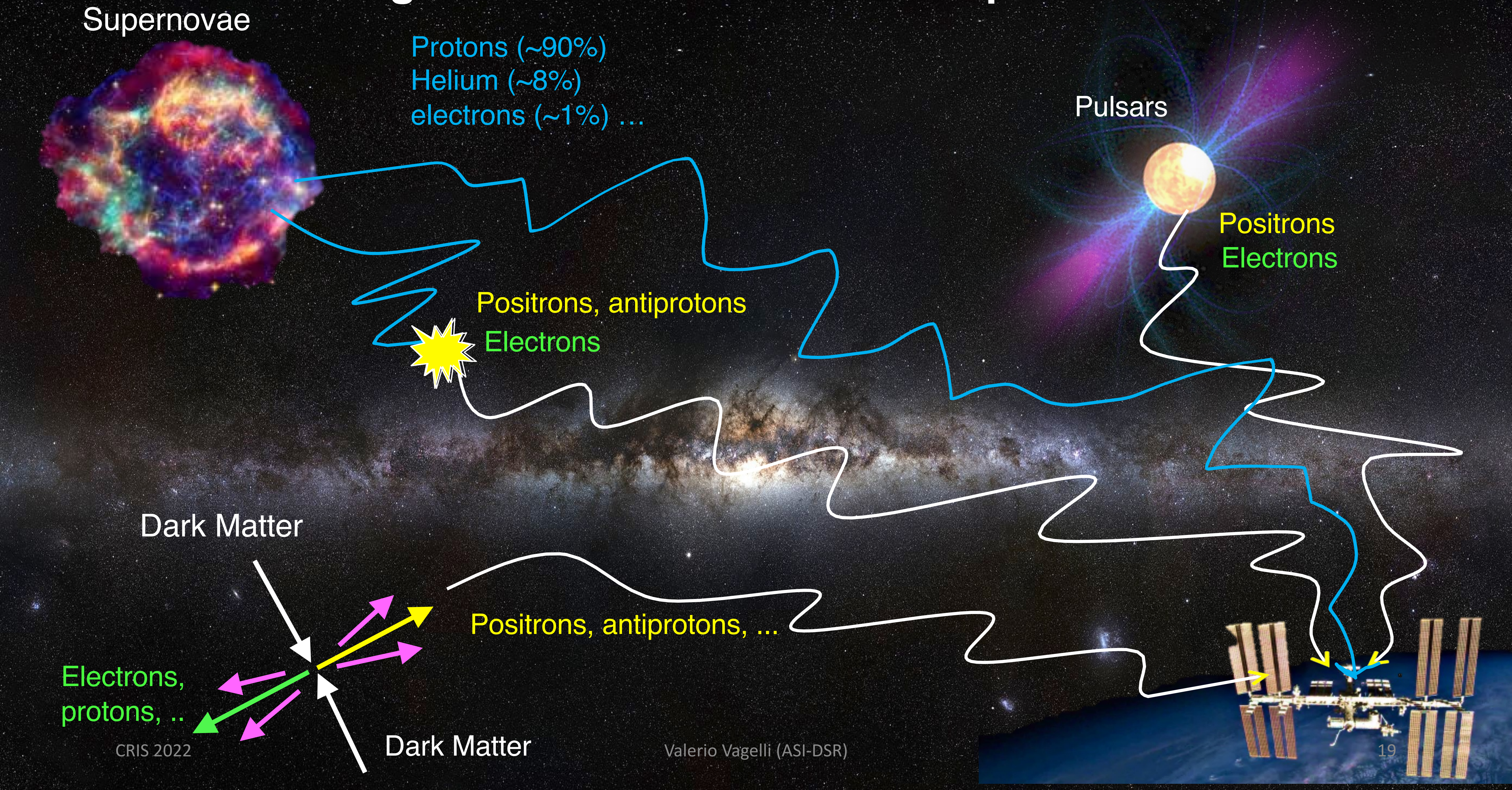
Rigidity spectra of **stably trapped nuclei** in the northern SAA extends from 1 to 5 GV. These populations are below the geomagnetic cutoff.

The chemical composition of up-going and down-going stably trapped nuclei is similar.

The charge distribution of stably trapped nuclei and GCRs is different (Li>C>O, while in GCRs O~C>Li)

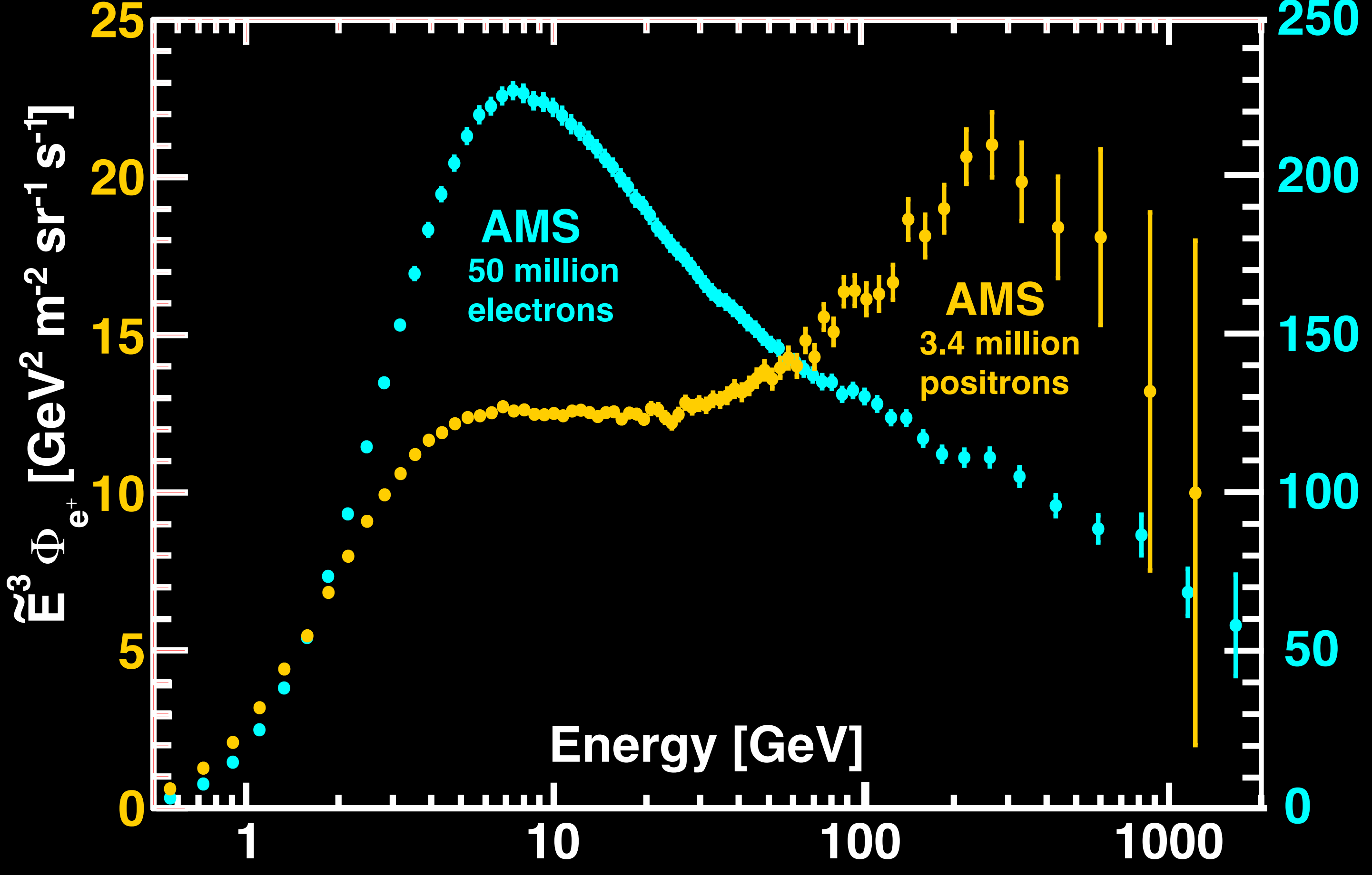
A stably trapped population has been clearly identified below 5 GV in the SAA region.
This population has properties (rigidity, charge, arrival direction) distinctly different from GCR.
This is a high-Z, high-energy population (up to 5 GV) never observed before.

Origin of cosmic electrons and positrons



Measurement of cosmic ray positrons and electrons

AMS 10 years update. First results in:
Phys. Rev. Lett. 113, 121101 (2014)
Phys. Rev. Lett. 122, 041102 (2019)
Phys. Rev. Lett, 122, 101101 (2019)

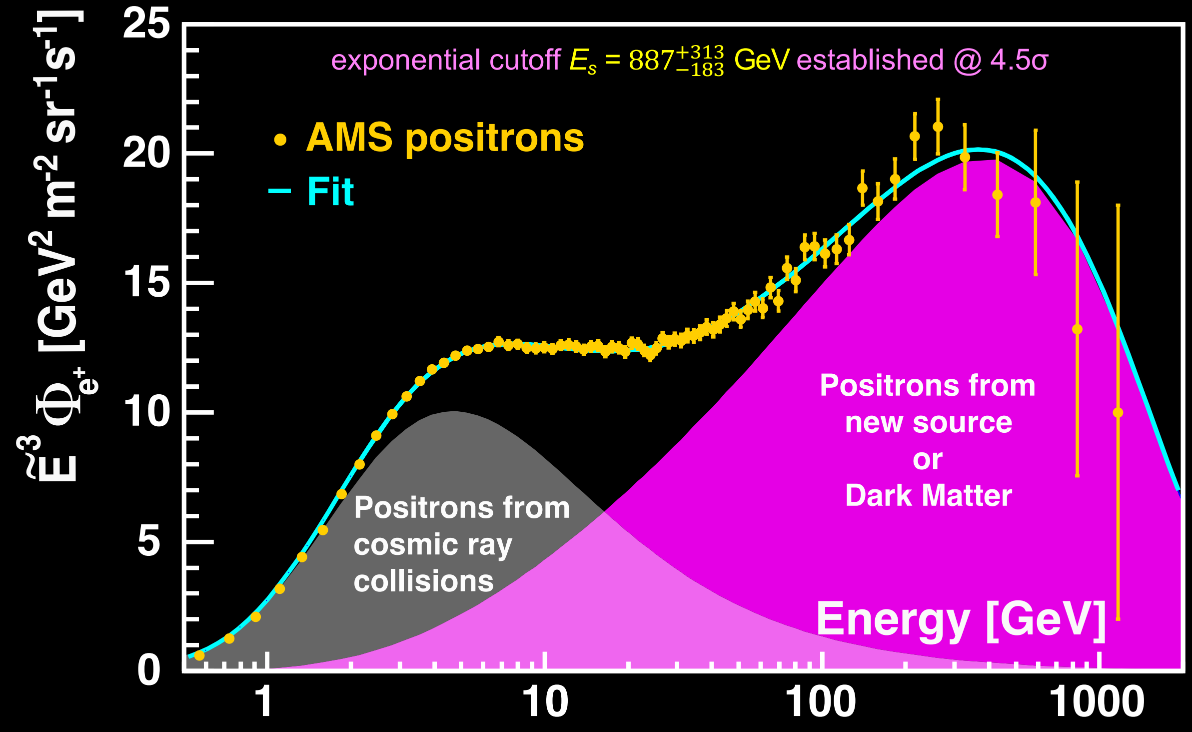


Measurement of cosmic ray positrons and electrons

The positron flux is the sum of low-energy part from cosmic ray collisions plus a high-energy part from a new source or dark matter both with a cutoff energy E_S.

Solar — Collisions — New Source or Dark Matter

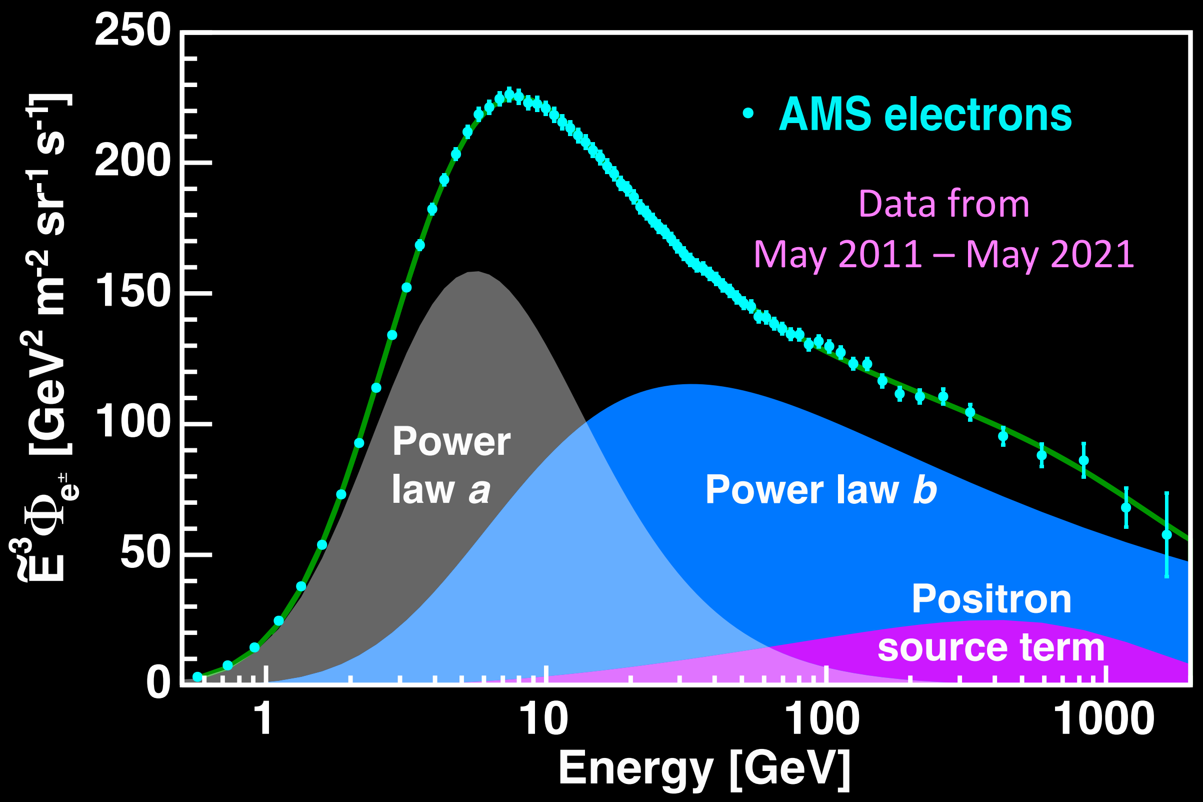
$$\Phi_{e^+}(E) = \frac{E^2}{\hat{E}^2}\left[C_d(\hat{E}/E_1)^{\gamma_d} + C_s(\hat{E}/E_2)^{\gamma_s}\exp(-\hat{E}/E_s)\right] \quad \hat{E} = E + \varphi_{e^+}$$



The electron spectrum favors the contribution of the positron source term (@95%C.L.)

$$\Phi_{e^-}(E) = S(E)\left[C_a(\hat{E}/E_a)^{\gamma_a} + C_b(\hat{E}/E_b)^{\gamma_b} + f_s\ C_s^{e^+}(\hat{E}/E_2)^{\gamma_s^{e^+}}\exp(-E/E_s^{e^+})\right]$$

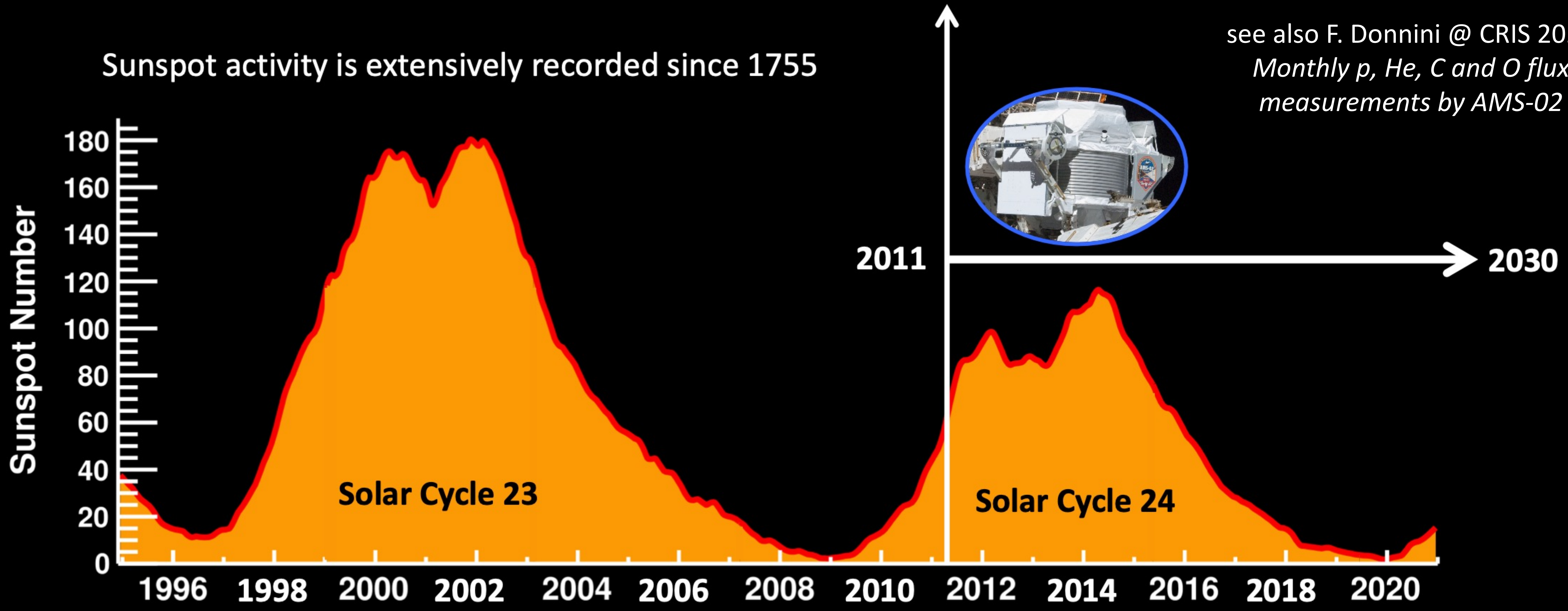
Fit result $f_s = 1.30 \pm 0.61$



Long-term and short-term variations in cosmic rays

Sunspot activity is extensively recorded since 1755

see also F. Donnini @ CRIS 2022
Monthly p, He, C and O flux measurements by AMS-02

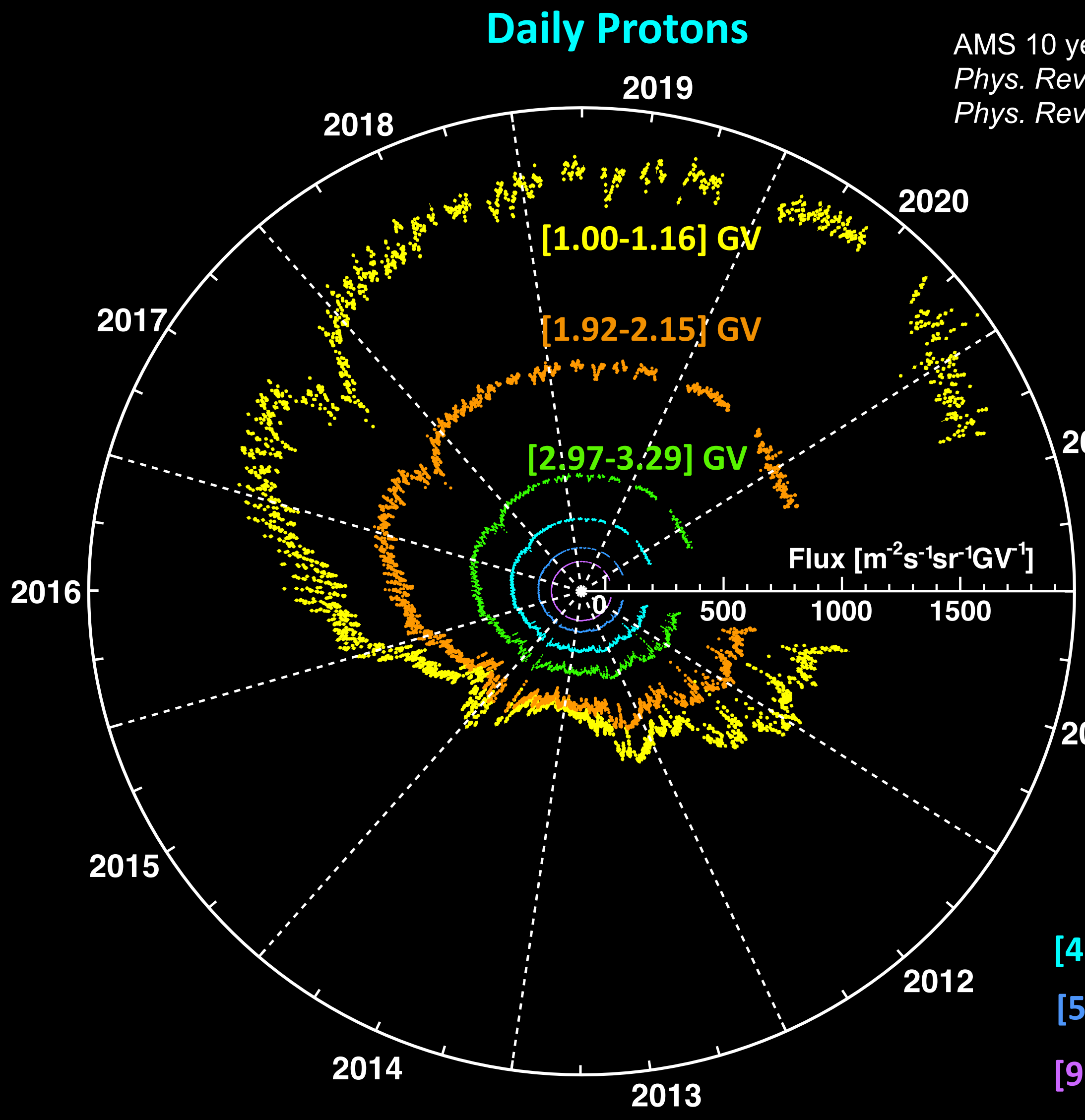


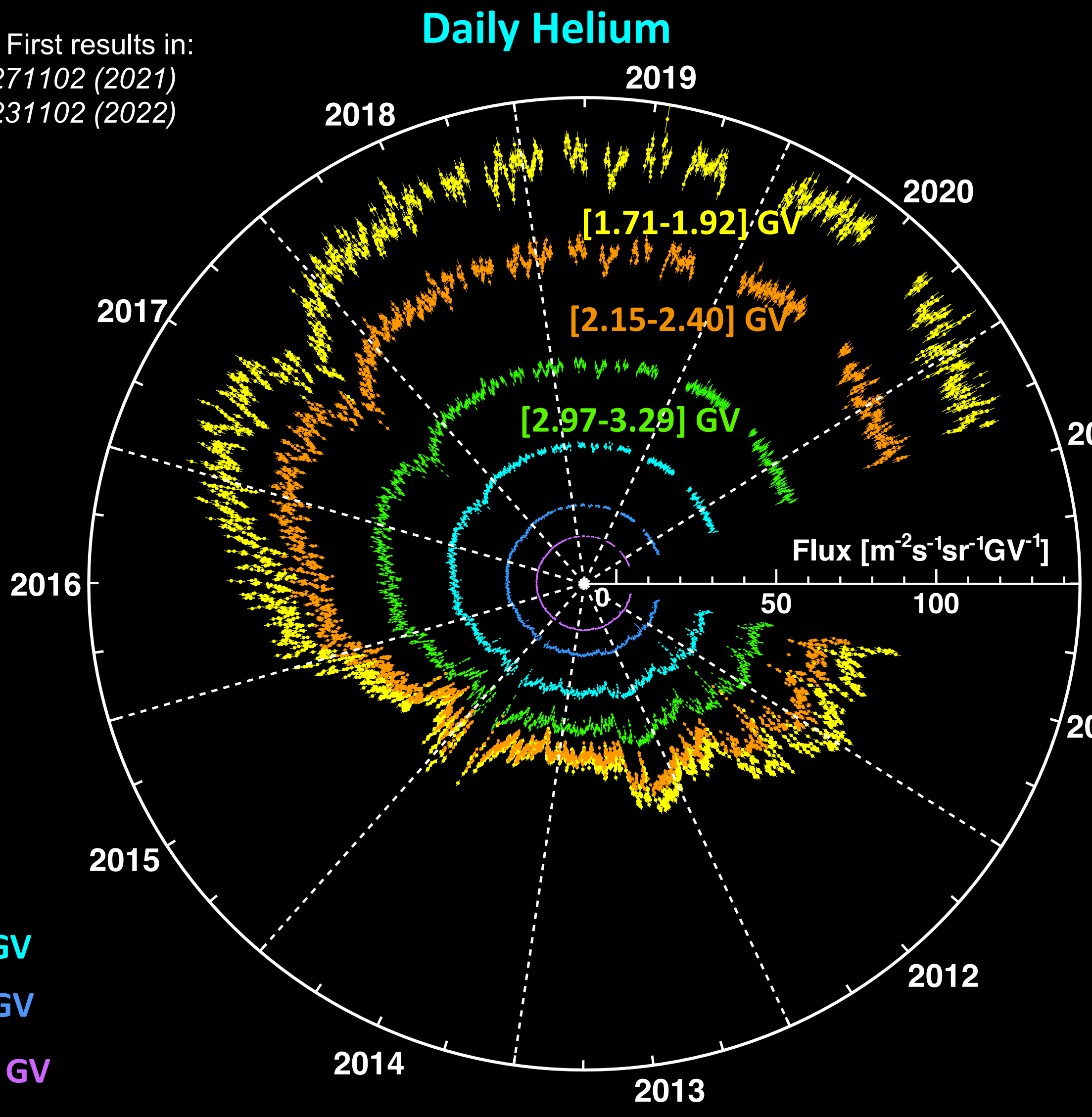
Cosmic ray long-term and short-term variations are unique probes of fundamental properties of solar system and provide safety information for interplanetary travel.

AMS Daily Proton and Helium Fluxes

6 billion protons and 850 million helium nuclei collected from **May 20, 2011** to **May 2, 2021**

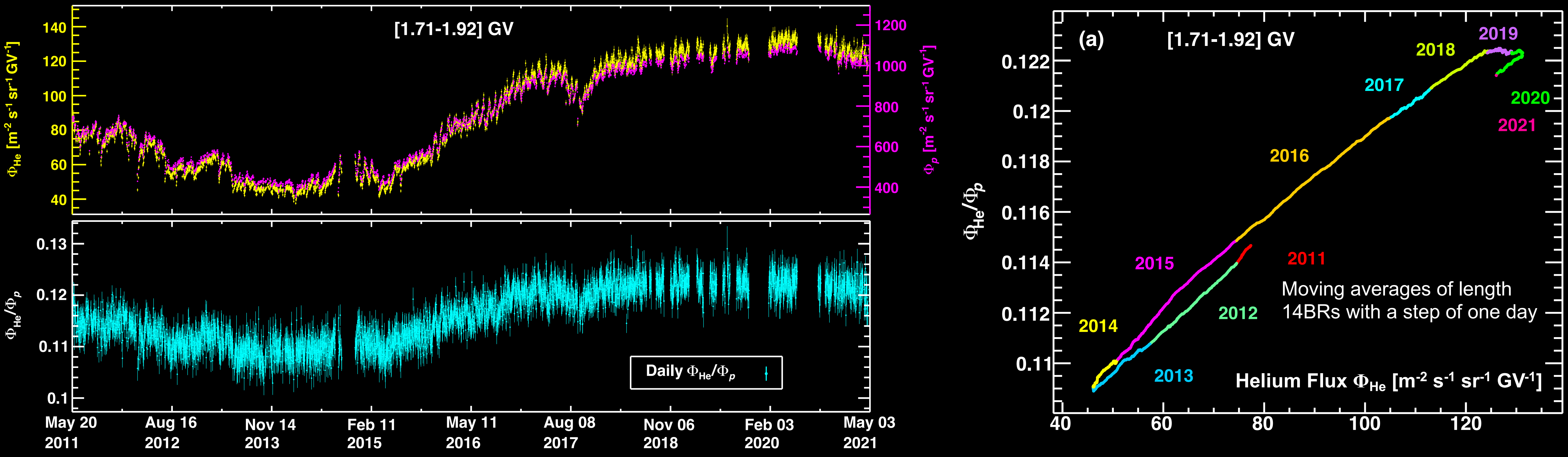
AMS 10 years update. First results in:
Phys. Rev. Lett. 127, 271102 (2021)
Phys. Rev. Lett. 128, 231102 (2022)





[4.02-4.43] GV
[5.90-6.47] GV
[9.26-10.10] GV

AMS Daily Proton and Helium Fluxes



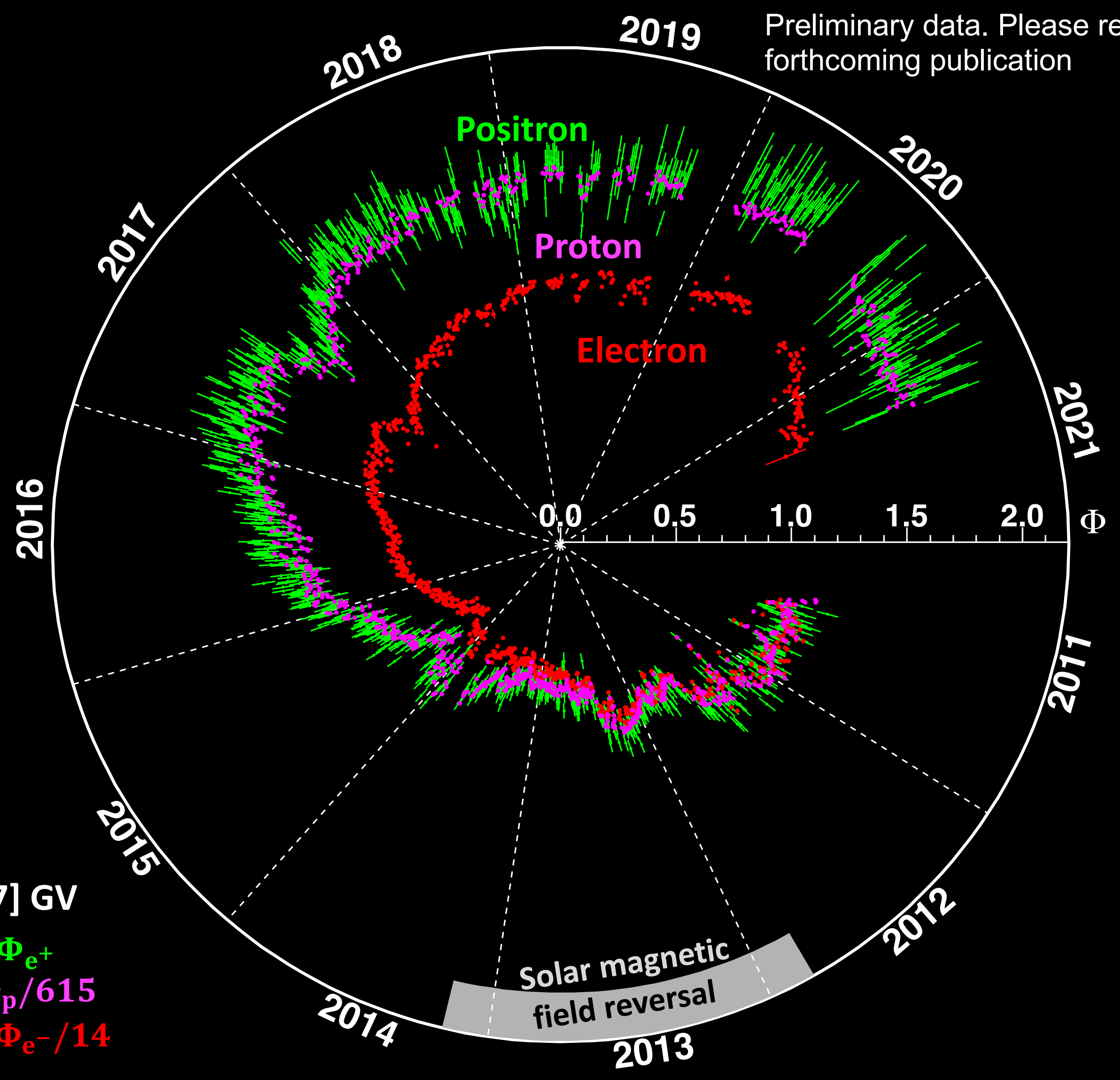
Proton and Helium fluxes exhibit short-term and long-term variations that depend on time and on rigidity.

The helium flux exhibits larger time variations than the proton flux.

At low rigidity the modulation of the helium to proton flux ratio is different before and after the solar maximum in 2014.

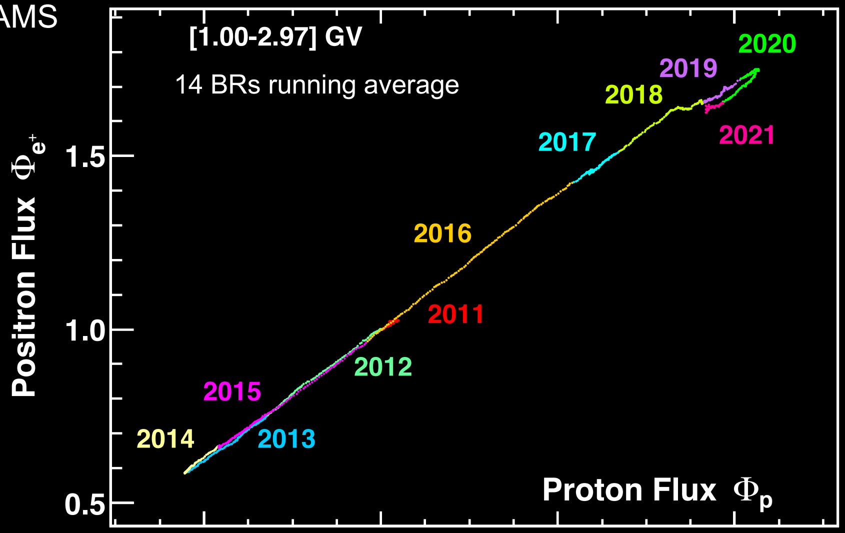
AMS Daily Electron and Positron Fluxes

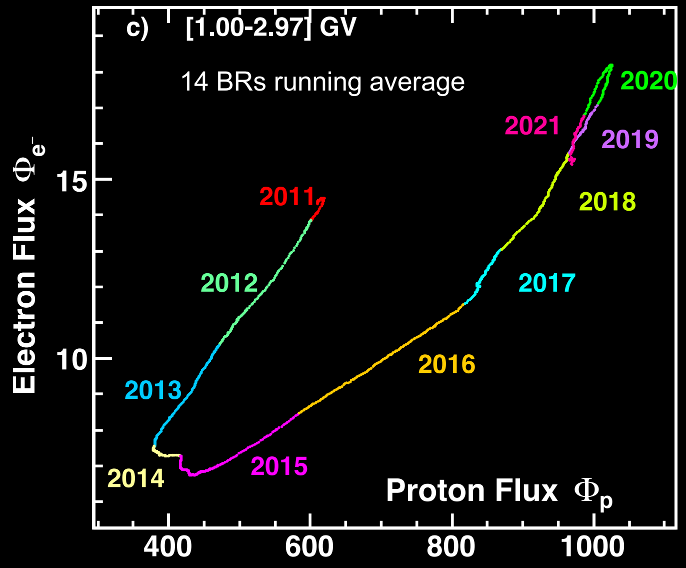
Preliminary data. Please refer to the AMS forthcoming publication



[1.00 - 2.97] GV

- Positron Φ_{e+}
- Proton $\Phi_p/615$
- Electron $\Phi_{e-}/14$





There is no other magnetic spectrometer in space in the foreseeable future.

By collecting data through the lifetime of ISS AMS should be able to determine the origin of the observed unexpected phenomena.

The AMS mission is supported by the Italian Space Agency under
ASI-INFN Agreement No. 2014-037-R.1-2017
ASI-INFN Agreement No. 2019-19-HH.0 and its amendments
ASI-University of Perugia Agreement No. 2019-2-HH.0

Agenzia Spaziale Italiana

AMS published data are available for access at Cosmic Ray Database hosted in ASI-SSDC
https://tools.ssdc.asi.it/CosmicRays/